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THE EFFECT OF SURFACE COATINGS ON THE FATIGUE STRENGTH OF ALUMINUM ALLOYS

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September 1981

U.S. ARMY MOBILITY EQUIPMENT
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An investigation to determine the effect of surface coatings on aluminum alloys and how the coatings affect the fatigue strength of aluminum in a positive or negative manner. Report includes details of laboratory tests comparing different anodic processes and surface treatments (shot peening).

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	metric ton	t
		VOLUME		
tsp	teaspoons	5	milliliters	mL
Tbsp	tablespoons	15	milliliters	mL
in^3	cubic inches	16	milliliters	mL
fl oz	fluid ounces	30	milliliters	mL
c	cups	0.24	liters	L
pt	pints	0.47	liters	L
qt	quarts	0.95	liters	L
gal	gallons	3.8	liters	L
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	degrees Fahrenheit	5/9 (after subtracting 32)	degrees Celsius	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares ($10\,000\ m^2$)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	metric ton (1000 kg)	1.1	short tons	
		VOLUME		
mL	milliliters	0.03	fluid ounces	fl oz
mL	milliliters	0.06	cubic inches	in^3
L	liters	2.1	pints	pt
L	liters	1.06	quarts	qt
L	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	degrees Celsius	9/5 (then add 32)	degrees Fahrenheit	°F

THE EFFECT OF SURFACE COATINGS ON THE FATIGUE STRENGTH OF ALUMINUM ALLOYS

I. INTRODUCTION

1. Statement of the Problem. Aluminum is a widely used metal in military applications such as vehicles, bridges, air-cushion vehicles, etc., but its use is limited to areas where the aluminum alloys would not be under load with variable or constant stresses and to areas where there would be almost no severe abrasion or corrosion. Anodic coatings tend to increase the abrasion and corrosion resistance of aluminum and its alloys, but the coatings have a detrimental effect on the fatigue endurance (in some instances by as much as 65 percent). The objective of this work was to provide a surface treatment and/or coatings that will allow the use of aluminum wrought alloys in any type of environment and that will be able to withstand the effects of abrasion and stress corrosion and temperature changes up to 344°F with an increased fatigue endurance.

2. Background. The favorable weight-to-volume ratio, ease of fabrication, availability in a wide variety of extruded and other forms, and easily applied wear- and corrosion-resistant anodic coatings make aluminum a highly desirable engineering material for many applications. One serious shortcoming of the use of hard anodized coatings on aluminum is that the electrolytic anodizing process may render certain of the alloys unsuitable for use as structural members by drastically reducing the fatigue strength (in some instances by as much as 65 percent). Numerous references in the literature indicate that anodic coatings are detrimental to fatigue properties of highly stressed specimens. Although the exact nature of fatigue failure has not been elucidated fully, the consensus is that it may occur because of stress concentration at the microcracks in the coating. Under repetitive applied loads, the basic metal loses its plasticity, resulting in the propagation of the local crack and reducing the cross sectional areas until finally the applied stress exceeds the static strength and causes failure. There is some evidence in the literature[1] that certain anodizing processes will reduce fatigue endurance to a smaller degree than the conventional anodizing; therefore, a wide variety of anodic coatings were studied. A successful surface treatment prior to anodizing was saturation shot peening per Military Specification MIL-S-13165. The peening action acts to impart a layer of compressive stresses on the surface, therefore increasing fatigue life, decreasing stress corrosion, and enhancing surface strength.[2]

---

1 S. Wernick and R. Pinner, Surface Treatment of Aluminum, 4th Edition (1972).

2 Metal Finishing Guidebook Directory, Metals and Plastic Publication, p. 90 (1981).

Shot peening[3] is also used to reduce surface tensile stresses in metal parts (such as axles, springs (helical, torsional, and leaf), gears, shafting, aircraft alighting gear and structural parts, etc.) which are subjected to repeated applications of complex load patterns for the purpose of improving resistance to fatigue and stress corrosion cracking. Shot peening is also used for applications such as closing porosity in castings and straightening or forming applicable parts, but for shot peening to have the desired effect, the specified intensity and coverage must be achieved on critical areas where high-tension stresses or stress ranges are most likely to cause fatigue or stress-corrosion failures in service. Actual experience with service failures or fatigue tests may be required to discover or confirm the location of such areas subject to critical stressing as a result of any combination of service, design, and manufacturing conditions. Aluminum alloys used for this work were 6061-T6 and 7075-T6.

II. EXPERIMENTAL PROCEDURE

3. Approach to the Problem. Commercially available surface treatments and anodizing processes were surveyed for evaluation purposes with respect to (a) fatigue endurance (25,000-lb/in.^{2} $\leq$ stress $\leq$ 35,000-lb/in.^{2}), (b) abrasion (wear) resistance, (c) degree of coating porosity (copper sulfate test), (d) resistance to thermal stress (344° F), and (e) resistance to corrosion (salt-spray test) of the unsealed coatings.

4. Selection of the Best Surface Treatment and/or Coatings. Aluminum alloys 6061-T6 and 7075-T6 were selected for this work because they are the alloys used most by the military. The aluminum alloys were prepared in the shape of fatigue coupons 1½ in. by 4 in. by 1/8 in. and abrasion resistance test panels 4 in. by 4 in. by 1/8 in. They were shot peened as specified by MIL-S-13165B and were anodized by different processes. The treated specimens were subjected to these tests: abrasion resistance, fatigue endurance, and degree of porosity. The tests were conducted before and after the specimens were submitted to the following tests: thermal stress (344° F) and salt-spray resistance. The anodizing techniques used were: low-temperature anodizing (28° F to 32° F or 48° F to 52° F),[3] regular anodizing (70° F),[4] pulse anodizing (55° F + 2°), Sanford low-voltage anodizing (40° F to 50° F),[5] and integral color anodizing (ICA-Duranodic 300)[5] at 70° F. The anodized specimens were not sealed in order to permit evaluation of the porosity of the coatings and their resistance to corrosion. All of these anodizing processes have a deleterious effect on the fatigue life of the aluminum alloys; the fatigue life is reduced from 300,000 cycles for untreated aluminum to as low as 95,000 cycles for regular anodizing at an applied stress level of 25,000 lb/in.^{2} In order to evaluate the effect of the combination of shot peening and a variety of anodizing processes, specimens were shot peened with S-280 shot to saturation (0.006 Almen) in accordance with Military

3 "Shot Peening of Metal Parts," Military Specification MIL-S-13165B.

4 "Anodic Coatings of Aluminum and Aluminum Alloys," Military Specification MIL-A-8625C.

5 Commercial anodizing processes.

Specification MIL-S-13165B and were anodized in accordance with the above-mentioned anodizing processes. Fatigue coupons were prepared in accordance with the instructions manual[6] for specimen No. 3. Coupons with round and sharp edges were included in order to evaluate the effect of the cracks and their propagation at the oxide coating-metal interface. Fatigue values for the test coupons were obtained at different loads (25,000 lb/in.^{2}, 27,500 lb/in.^{2}, 30,000 lb/in.^{2}, 32,500 lb/in.^{2}, and 35,000 lb/in.^{2}) by using Baldwin Universal Model SF-2 and Satec[6] Models SF-2U-144 and -145 fatigue testing machines. The abrasion (wear) resistance, the thickness, and the corrosion resistance of the specimens were determined in accordance with Military Specification MIL-A-8625C.[4] The results obtained from the different tests (fatigue endurance, abrasion resistance, and degree of porosity) are shown in Tables 1 and 2.

The scanning electron microscope (SEM) was used at several magnifications in order to observe the effect of shot peening and several anodizing processes on the surfaces of the aluminum alloys. The observations (Figures 1 through 9) were made before and after the alloys had been tested for fatigue endurance, thermal stress, and resistance to corrosion. All micrographs used throughout this report were taken at 100X magnification and are representative of the alloys, shot peening, and different anodizing processes used; for practical purposes, no visual differences could be found between the different coatings before and after each test.

III. DISCUSSION

5. **Results.** The values obtained before and after the exposure of the coated samples to the salt-spray test (336 hours) and to a temperature of 344° F (20 hours) with respect to fatigue endurance, abrasion resistance, and degree of porosity were within the allowed statistical deviation. An examination of the laboratory data mentioned above indicates that any anodic coating has detrimental effects to the fatigue endurance of aluminum. The data also indicate that the combination of integral color anodizing (ICA) or hard coat MIL-A-8625C, Type III with saturation shot peening per Military Specification MIL-S-13165B have a beneficial effect on the fatigue endurance of aluminum alloys 6061-T6 and 7075-T6 fatigue coupons with round and sharp edges. In addition, by imparting a compressive surface strength, a greater stress load is needed to fracture the coupon. The data also indicate that coupons with sharp edges do not have a fatigue life as long as the coupons with rounded edges, probably because of the many cracks or imperfections of the edges present in the former coupons; therefore, sharp edges should be finished or rounded by shot peening or sandblasting in order to diminish the possibility of crack propagation.

[4] "Anodic Coatings for Aluminum and Aluminum Alloys," Military Specification MIL-A-8625C.

[6] Satec Systems, Inc.; Grove City, PA 16127.

Table 1. Aluminum Alloy 6061-T6

Surface Treatment	Thickness (mils)	Fatigue Endurance (Kilocycles) Coupons With: Round Edges	Fatigue Endurance (Kilocycles) Coupons With: Sharp Edges	Abrasion Resistance Unsealed Coatings Weight Loss (mg/10,000 c)	Unsealed Coatings as Received	Porosity Test**: Heated for 20 h @344° F	Porosity Test**: Salt-Spray Test (Unsealed Coatings)
None	N/A	(a) 300-400 (b) 200-300	(a) 200-300	N/A	N/A	N/A	Light
All anodizing processes w/o shot peening	0.8-1.5	(a) 50-250	(a) 50-100	15-25	Not tested	Not tested	Not tested
Shot peening and integral color anodizing (ICA)	1.0	(a) 7909 (b) 100-300	(a) 874	17.8	Light population	Light population	Light corrosion
Shot peening MIL-A-8625 Type II	0.9	(a) 520 (b) 100-300	(a) 369	16.8	Light population	Light population	Moderate corrosion
Shot peening and MIL-A-8625 Type III	1.5	(a) 2405* (b) 100-300	(a) 436	18.0	Light population	Light population	Light corrosion
Shot peening anodized hard coat (AHC) duplex coating	1.5	(a) 1597* (b) 100-300	(a) 312	20.4	Negligible	Negligible	Light corrosion

(a) 25,000 lb/in.^{2}
(b) 30,000 lb/in.^{2}
*Sample did not fail.
**Density of the metallic copper specks on the test site (visual inspection) – the heavier the density (population), the greater the porosity.

Table 2. Aluminum Alloy 7075-T6

Surface Treatment	Thickness (mils)	Fatigue Endurance (Kilocycles) Coupons With Round Edges	Fatigue Endurance (Kilocycles) Coupons With Sharp Edges	Abrasion Resistance Unsealed Coatings Weight Loss (mg/10,000 c)	Unsealed Coatings as Received	Heated for 20 h @344° F	Porosity Test** Salt-Spray Test (Unsealed Coatings)
None	N/A	(a) 300-400 (b) 200-300 (c) 500-600 (d) 50-70	(a) 200-300	N/A	N/A	N/A	Light
All anodizing processes w/o shot peening	0.8-1.5	(a) 50-100 (b) 30-50 (c) 20-30 (d) 15-20	(a) 40-50	10-25	Light population	Light population	Not tested**
Shot peening and integral color anodizing (ICA)	1.0	(a) 14845 (b) 1951 (c) 1276 (d) 1072 (e) 144	(a) 213 (b) 239 (c) 381 (d) 243 (e) 81	24.0	Light population	Hvy population	Moderate corrosion
Shot peening and MIL-A-8625 Type II	0.9	Not tested	Not tested	20.0	Light population	Hvy population	Not tested***
Shot peening and MIL-A-8625 Type III	1.5	(a) 1500	(a) 360	19.1	Moderate population	Moderate population	Not tested***
Shot peening and anodized hard coat (AHC) duplex coating	1.5	(c) 1312*	(a) 1666 (b) 248 (c) 237 (d) 102	119.9	Light population	Light population	Not tested***

(a) 25,000 lb/in.²
(b) 27,500 lb/in.²
(c) 30,000 lb/in.²
(d) 32,500 lb/in.²
(e) 35,000 lb/in.²
* Sample did not fail.
** Density of the metallic copper specks on the test site (visual inspection) – the heavier the density (population), the greater the porosity.
***Processed Coupons Not Available

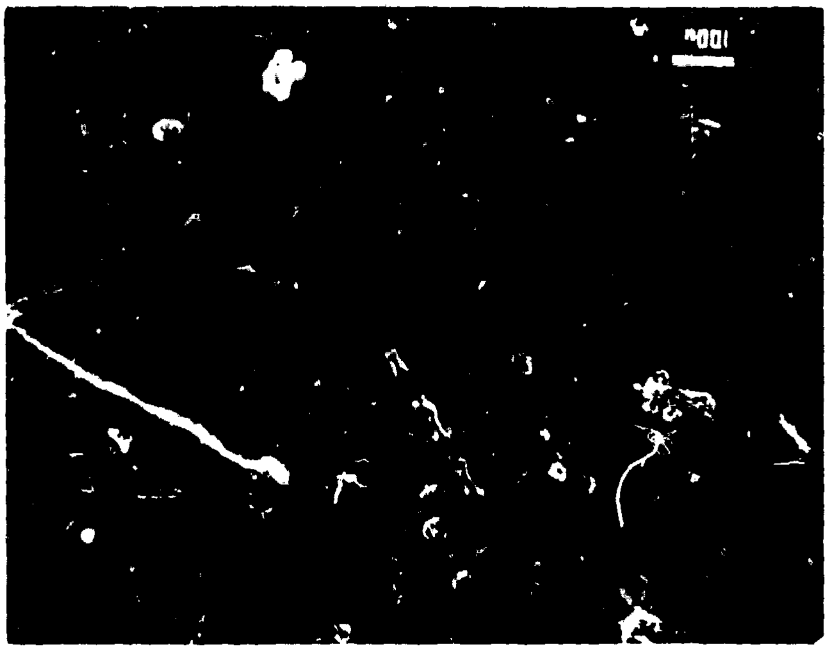

Figure 1. Untreated top surface.
The surface is uniform with some imperfections. Because of the uniformity, once a crack is initiated it grows and propagates until there is a fracture.

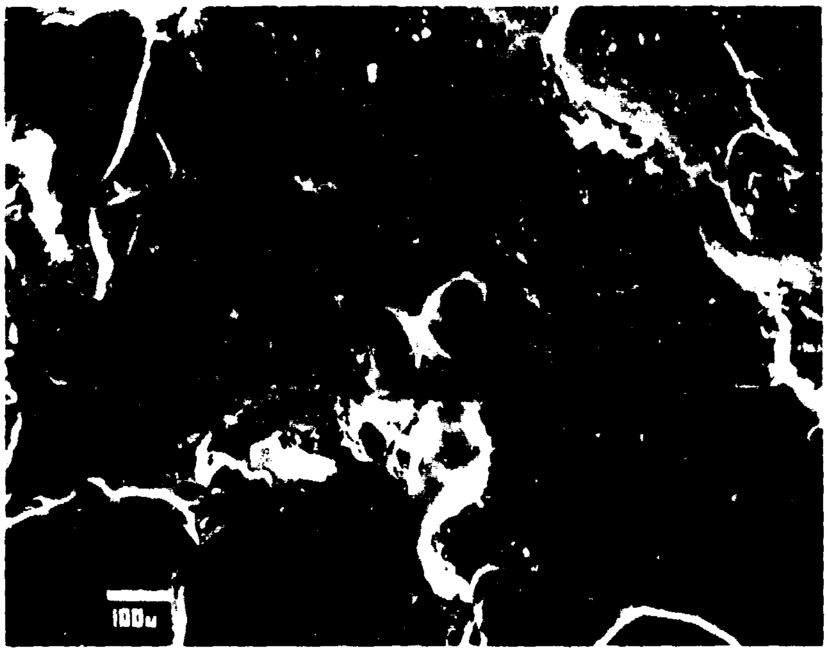

Figure 2. Shot-peened top surface.
Shot peening distorts the surface, impeding or slowing the growth and propagation of a crack.

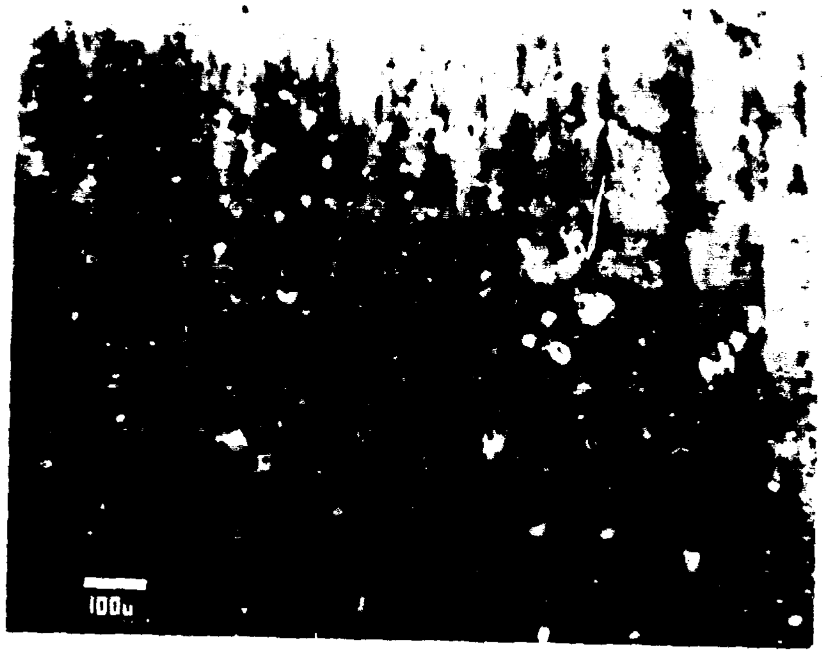

Figure 3. Anodized-unsealed top surface.
Anodic coatings tend to emphasize the surface defects and imperfections accelerating crack growth and its propagation until fracture occurs.

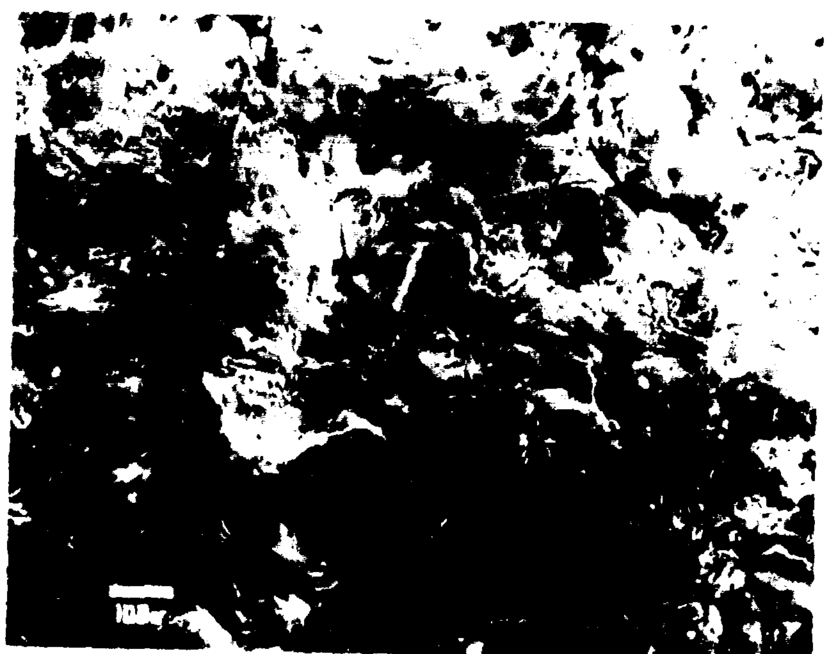

Figure 4. *Shot-peened* and anodized-unsealed top surface.
The top anodic coating layer evens out the deformation (visual appearance) produced by the shot peening. The main purpose for anodizing a shot-peened surface is to increase the corrosion and abrasion resistance of the shot-peened surface so as to retain the increased fatigue endurance.

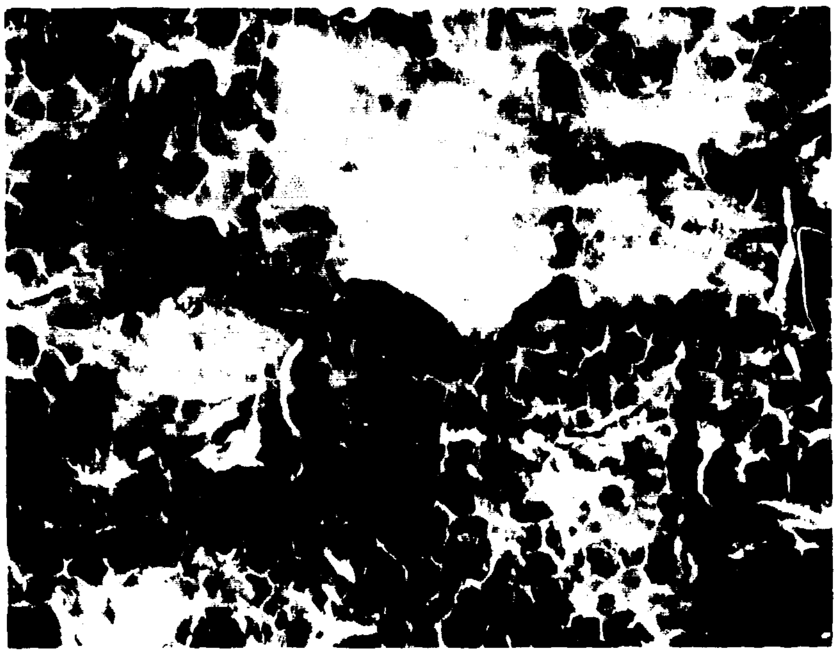

Figure 5. Shot-peened and anodized-unsealed coating heated to 344° F (20 hours) and exposed to salt-spray test (336 hours).

When anodic coatings are heated, they craze. The corrosion of the alloy seems to initiate at the intersection of the microcracks which grow and propagate until the substrate fails.

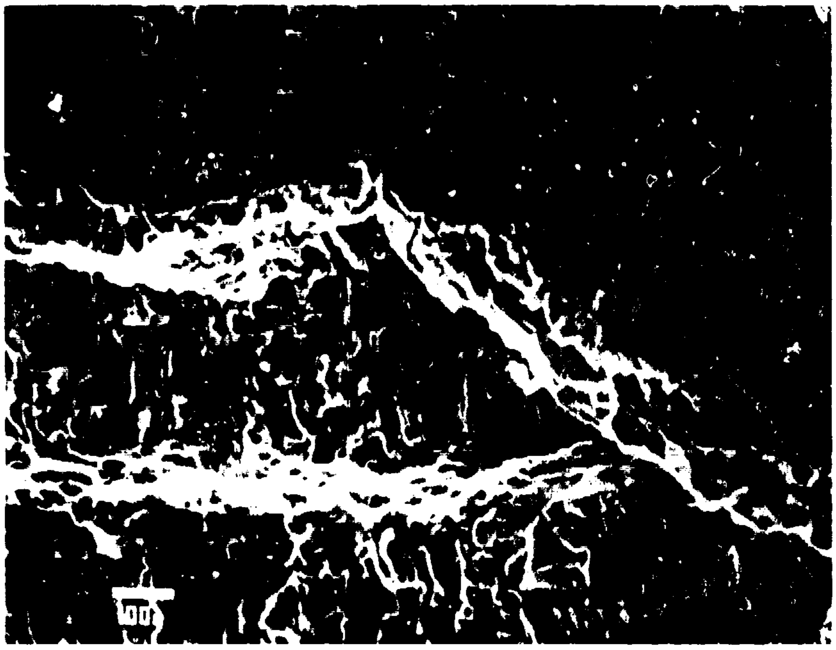

Figure 6. Untreated surface—fracture of the fatigue coupon (vibrating end). The smooth area at the top of the micrograph is the region of the initial propogation of the crack. This region has been worn by rubbing against the stationary end of the coupon. Once the flexural or bending stresses reach a critical area in the coupon, the crack propagates quickly and a brittle fracture occurs, leaving a rough textured surface as in the lower part of the micrograph. The bands where the light intensity is higher indicate changing depth levels.

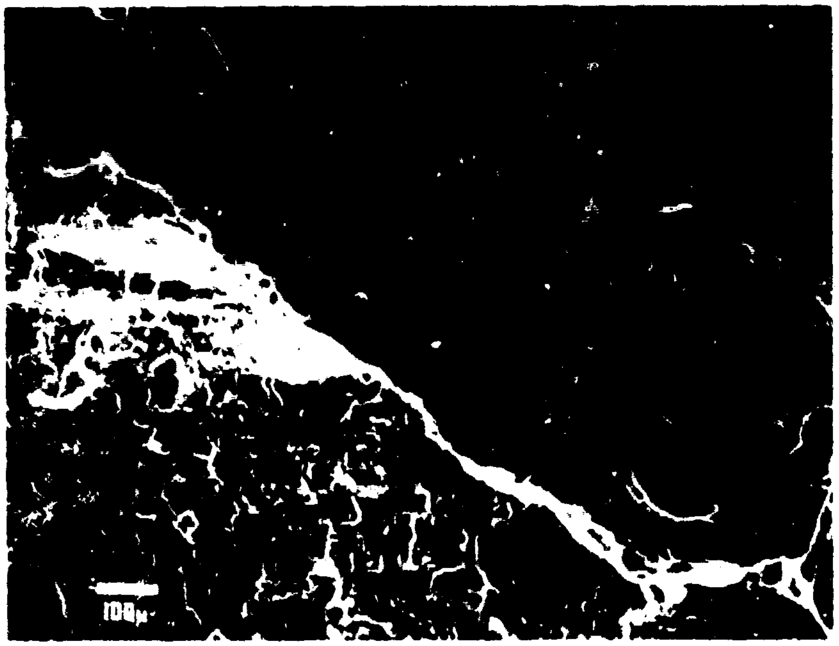

Figure 7. Shot-peened surface—fracture of the fatigue coupon (vibrating end). The same comments for Figure 6 apply to Figure 7. The change in depth in the initial area of propagation appears as waves. These depth changes occur when the crack encounters an imperfection of lower stress strength running at an angle to the fracture plane, and the crack propagates along the path of least resistance.

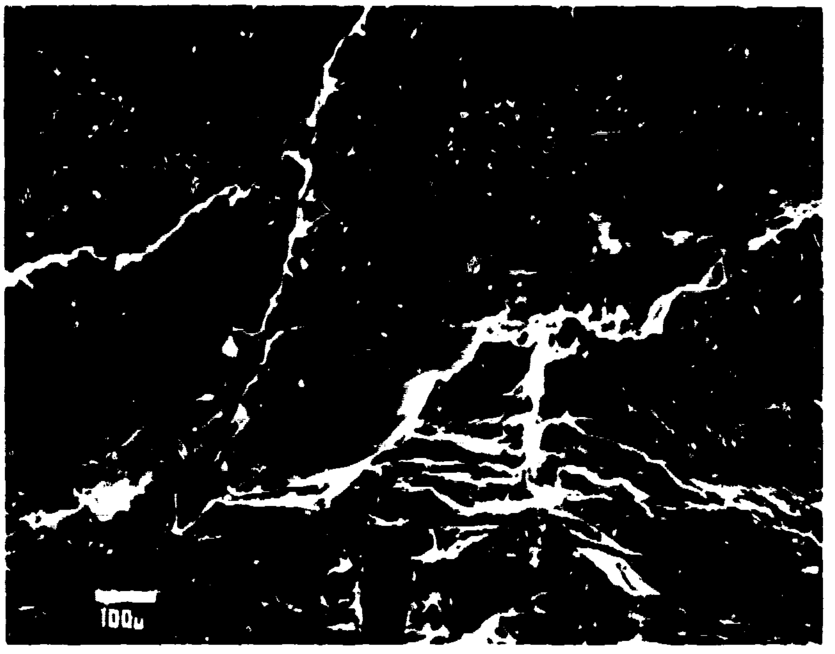

Figure 8. Shot-peened surface with an unsealed anodic coating—fracture of the coupon (vibrating end).
The same comments for Figures 6 and 7 apply to Figure 8. The wear pattern of the fracture indicates horizontal and vertical vibrations.

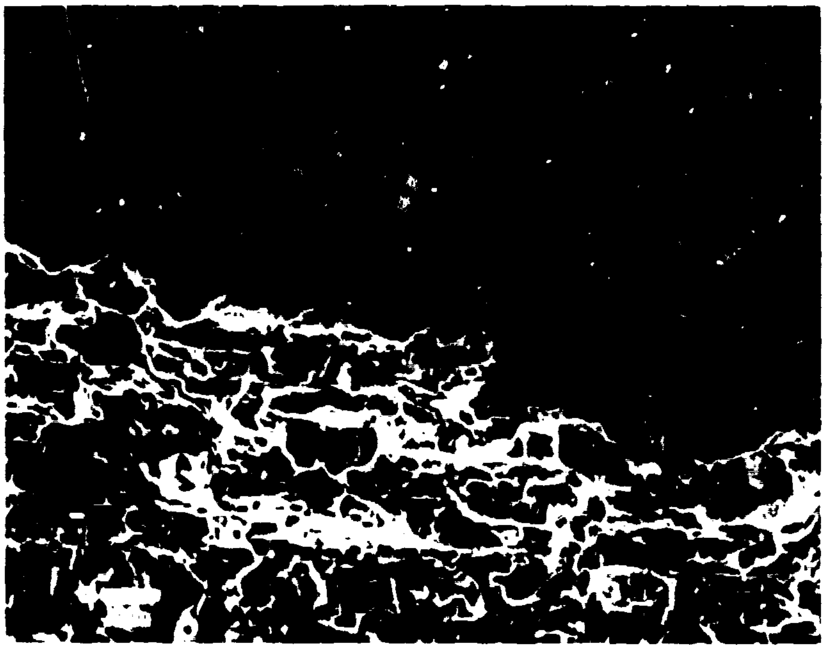

Figure 9. Unsealed anodic coating—fracture of the coupon (vibrating end).
The same comments for Figure 6 and 7 apply to Figure 9. The ridges on the initial areas of propagation were caused by imperfections on the stationary end rubbing into the vibrating end.

An additional analysis of the data indicates that anodizing per MIL-A-8625C Type II should be avoided if the specimen is going to be under stress because this anodizing process tends to decrease drastically the beneficial effects of shot peening. The compressive layer imparted by the shot peening process will provide an increased fatigue life, but the layer will lose its effectiveness in a corrosive environment and in contact with dissimilar metals because the compressive layer does not have any corrosion resistance properties. The purpose of the anodizing as a superficial layer over the shot peening is to protect the compressive layer in a corrosive environment and to provide an abrasion-resistant coating. Shot peening increases the fatigue life, diminishes the possibility of stress corrosion cracking in susceptible alloys, and increases the surface strength; the anodic coating increases the wear and corrosion resistance (the coating could be sealed either with Teflon or a duplex seal or a lubricant). The combination of the shot peening and the anodic coating (ICA or Type III) will allow the use of aluminum and its alloys in many environments for applications where it could not be used previously. A word of caution with respect to shot peening: the peening of very thin or small sections to high intensities should be avoided because of the distortion and high-residual tensile stresses in the core material that may result from such peening. This is particularly true when the part has surfaces finished after heat treatment or is used as a tension member.

IV. CONCLUSIONS

6. Conclusions. It is concluded that:

a. The combination of saturation shot peening per Military Specification MIL-S-13165 and integral color anodizing (ICA-Duranodic 300 process) or MIL-A-8625 Type III, will result in aluminum with an anodic coating that has increased fatigue endurance, is less susceptible to stress corrosion cracking, and has enhanced surface strength. The above-mentioned surface treatment will allow the use of aluminum wrought alloys in any type of environment and be able to better withstand the effects of abrasion and stress corrosion, temperature changes up to 344° F with an increased fatigue endurance.

b. The ICA hard coat process will be cost effective when compared to the Type III coating because the former is a 70° F process, meanwhile, the Type III process requires low temperature (28° to 32° F or 48° to 52° F).

BIBLIOGRAPHY

Beitel, G. A. and C. Bowles, "Influence of Anodic Layers on Fatigue-Crack Initiation in Aluminum," *Metal Science Journal*, pp. 85-91 (1971).

Bowers, J. E. and N. J. Finch, "The Fatigue Behavior of Bolted Joints in an Aluminum – 5½% Zinc – 2½% Magnesium – 1½% Copper Alloy," *Journal of the Institute of Metals*, pp. 239-244 (1972).

Frisbee, L. E., "The Lockheed Tri Star – An Operational Overview," *Aeronautical Journal*, pp. 389-402 (Sep 74).

Harris, F. and S. Levine, "Development of a Continuous Hard Anodized Aluminum Surface," US Army Mobility Equipment Research and Development Command Report No. 1952 (May 69).

Larsson, N. and L. Jarfall, "Fatigue Tests with Tunnel, Notched Specimens of Forged Aluminum 3633-4 of Various Surface Treatments," The Aeronautical Research Institute of Sweden. Technical Note, FFA HU-1729.

Murphy, M., "Technical Developments in 1979 (Inorganic Metallic Finishes, Processes, and Equipment)," *Metal Finishing*, p. 21 (Feb 80).

Wood, J. R., "Surface Effects of the Stress Corrosion of 7075-T6 Aluminum Alloy," *Current Engineering Practices*, pp. 20-27 (1971).

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